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Active solar heating systems for energy efficient buildings in Greece: A technical economic and environmental evaluation

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ABSTRACT

The purpose of this study is the technical and economic evaluation of a typical solar space and water heating system, utilized in an 88 m^2 detached house that is designed according to the latest Greek Regulation on the Energy Performance of Buildings as a means toward Nearly Zero Energy Buildings (NZEB). The analysis was conducted for each of the four climatic zones designated in the Greek Regulation. A financial analysis was performed and the Net Present Value and the Discounted Payback Period (DPBP) were calculated and correlated with the solar systems collector area and the storage tank volume. Furthermore, the annual avoided emissions from the substituted fossil fuels are estimated for the solar systems considered. The analysis demonstrates that the typical solar space and water heating system can provide a viable solution toward NZEB with solar coverage and DPBP being strongly influenced by the climatic zone of the building and the type of fossil fuel substituted. In all cases the solar system covers at least 45% of the total heating loads while the payback period is as low as 4.5 years with an annual abatement of more than 50 t of CO_2 in the worst case scenario.

1. Introduction

Heating and cooling account for a significant portion of the world's total energy demand. The building sector in particular is responsible for more than 40% of the final energy consumption in the European Union (EU) with space heating representing 68% of the total household consumption, followed by water heating at 12% in 2009 [1]. In an effort to reduce CO_2 emissions and promote the use of renewable sources, the EU passed the Directive 2009/28/EC [2] which implied that the member states should increase the use of renewable energy sources along with energy efficiency and savings by 20% until 2020. A further 80% reduction in the energy consumption of the existing building stock, relative to the 2010 levels by 2050, was recently passed in the European Parliament (March 2013). The Directive 2010/31/EC [3] defined minimum rules on the performance of buildings introducing energy certificates, taking into account the external climatic conditions and defining the NZEB. Furthermore, 2018 was set as the year in which all new buildings occupied or owned by public authorities ought to be NZEB with the rest of the new building stock following at 2020.

A building has to exhibit a very high energy performance in order to qualify as a NZEB. Furthermore, the amount of energy required should be covered by energy from renewable sources to a very significant extent including energy from renewable sources that is produced on-site or nearby.

Although domestic solar hot water systems (DSHWS) is a widely accepted concept for hot water production with a high level of market penetration, solar space heating systems have rather low levels of market penetration and public acceptance despite being a mature technology. During the last decades, solar collectors for space and water heating matured significantly providing a reliable alternative to fossil fuels or electricity [4]. Particularly in Greece, DSHWS present a mature and widely available technology with an installed capacity of 4.1 million m^2 (2.8 MWth) at the end of 2011, placing Greece third in the per capita installed capacity in the EU [5]. Solar space heating systems from a niche market, mainly in the countries of North and Central Europe [6], currently present not only a flourishing market all over Europe but also a viable solution toward NZEB.

In the present work, a feasibility analysis is performed concerning various typical solar space and water heating systems utilized in a representative 88 m^2 detached house designed according to the latest Greek Regulation of the Energy Performance of Buildings (KENAK) [7], which is in accordance with the Directive 2010/31/EC [3]. The analysis was conducted for each of the four climatic zones designated in KENAK in order to find the best techno-economic solution possible.

The widely used f-chart method was implemented for the energy calculations regarding the proposed solar systems, while

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Nomenclature

U_i	heat transfer coefficient (W m^{-2} K^{-1})
A_i	building element area (m^2)
α	absorptivity
ε	emissivity
F_RU_L	collector losses (W m^{-2} K^{-1})
$F_R(\tau\alpha)_n$	collector efficiency
NPV	Net Present Value of the investment (€)
DPBP	Discounted Payback Period (years)
IC	initial cost of investment (€)
n	expected lifetime of the project (years)
R_t	expected cash flows (revenues)
i	energy inflation
r	real average interest rate

software (TEE-KENAK) based on the EN 13790 [8] methodology was used for calculating the heating loads of the buildings. Furthermore, a financial analysis was performed and the NPV and DPBP were calculated for every case. Finally, the annual abated Green House Gases (GHG) from the substituted fossil fuels were also estimated.

2. Description of the building and the solar system

In 2010 three million tons of oil equivalent were consumed for space heating in the building sector, representing more than 64% of the total final energy consumption in Greece, while water heating accounted for 6% [9]. With the incorporation of the Directive 2010/31/EC in the Greek Regulatory Framework, energy consumption for heating is predicted to decline from an average of more than 100 kWh/m^2 yr to as low as 15 kWh/m^2 yr [10,11] making the use of solar space heating systems viable from an economic point of view.

Currently, more than 29.5% of all the residences in Greece have a surface area between 75 and 99 m^2 while the average household, excluding one-person households, consists of 3.5 members on average [12]. For these reasons a south oriented 88 m^2 detached house with a flat rooftop, covering the needs of a four-member family, was simulated with the software (TEE-KENAK) in order to evaluate the efficiency of a typical NZEB [13]. The building has a rectangular shape with 8 m width and 11 m length, a flat terrace and an internal height of 3 m. The orientation and the openings in all sides of the building are presented in the plan view in Fig. 1.

In order to cover all the climatic zones defined in KENAK, the analysis was conducted for the four larger (in population) cities as representative of each zone, namely: Heracleion (35.20° N, 25.08° E), Athens (37.50° N, 23.45° E), Thessaloniki (40.30° N, 22.58° E) and Florina (40.60° N, 21.26° E) (Fig. 2). It has to be noted that the above four cities cover more than 60% of the total population of Greece [12]. The total area of the structural elements of the building in the four main orientations, the heat transfer coefficient of each element, as well as the average heat transfer coefficient of the building are presented in Table 1 and they are in accordance with KENAK.

The house was outfitted with a typical solar space and water heating system, coupled with an auxiliary fossil fuel heater (oil for all cases, oil or natural gas for Thessaloniki and Athens where grid infrastructure is available) as shown in Fig. 3. The solar system consists of typical selective flat plate collectors and a hot water storage tank with a backup boiler. The system was designed to be combined with fan coils, which is the usual practice for low temperature systems with auxiliary conventional fossil fuel boilers in order to provide space heating and it also covers domestic hot water needs. As per regulation, all heat distribution pipes were thermally insulated and the solar system uses variable speed pumps with recirculation.

Nine different sized systems were considered in order to investigate the influence of the solar collector area and the storage tank volume of the solar heating system for the four climatic zones.

The technical characteristics of the solar system components are presented in Table 2 while the total cost of the different systems considered is presented in Table 3.

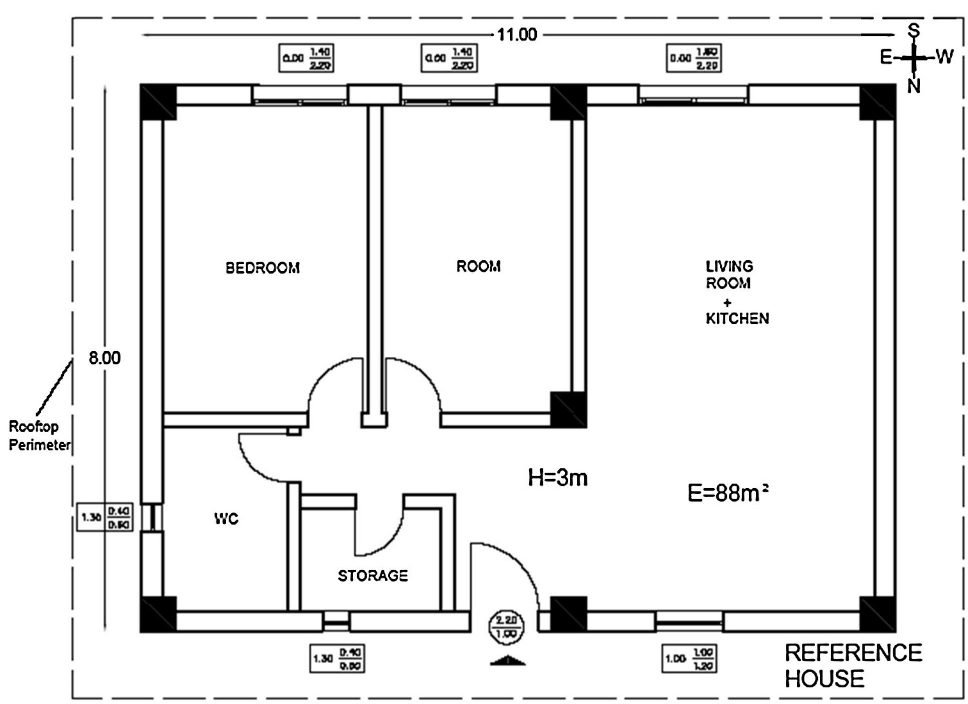

Fig. 1. Plan view of the reference building.